AMYLOGRAPH PROPERTIES OF BREAD CRUMB AND THEIR RELATION TO CRUMB FIRMNESS

by

ANSUI XU

B.E., Wuxi Institute of Light Industry, 1982

A MASTER'S THESIS

Submitted in partial fufillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1986

Approved by:

Co-major Professor

Co-major Professor

TABLE OF CONTENTS

Page

LIST OF TABLES iii

LIST OF FIGURES iv

INTRODUCTION 1

LITERATURE REVIEW 3

I. Use of Amylograph in Determining Pasting Properties of Bread Crumb 3

a. Basis of using amylograph in studying bread crumb 3

b. The unique features 4

c. Sample preparations 5

d. Influencing factors 6

II. Bread Staling 7

III. Changes of Starch during Amylograph Tests 9

MATERIALS AND METHODS 12

I. Materials 12

a. Flour 12

b. Yeast 12

c. Shortening 12

d. Surfactants 12

e. Starch 13

II. Methods 13

a. Amylograph 13

b. Amylogram characteristics 14

c. Baking formula 17

d. Baking procedure 17
e. Firmness measurement 18
f. Fat extraction and impregnation 18
g. Moisture measurement 19
h. Storage test procedure 19
i. Statistical analysis 20
RESULTS AND DISCUSSION 23
I. The Cause of the Unique Characteristics of Bread Crumb Amylograms 23
a. The approach to the problem 23
b. Description of the bumps in amylogram 34
c. Discussion of bump formation 38
II. Results of the Storage Test and Relation of Crumb Amylogram Readings to Crumb Firmness 46
a. Moisture content of the bread crumb.....46
b. Effects of storage times on crumb amylogram readings 49
c. Effects of treatments on crumb amylogram readings 54
d. Effects of shortening, lipids and surfactants on loaf volume and crumb firmness 62
e. Relation of crumb amylogram readings to crumb firmness 67
CONCLUSIONS 75
ACKNOWLEDGMENT 77
REFERENCES 78

LIST OF TABLES

Page

Table 1. Bump area and temperature range of flour amylogram with repeated cycles 35

Table 2. Crumb amylogram readings and crumb moisture of bread made without shortening at different storage times 47

Table 3. Crumb amylogram readings and crumb moisture of bread made with shortening at different storage times 48

Table 4. Pasting temperatures and other characteristics of amylograms of bread crumb without shortening 50

Table 5. Pasting temperatures and other characteristics of amylograms of bread crumb with shortening 51

Table 6. Comparison of bread amylogram readings among storage days 52

Table 7. Comparison of amylogram readings on bread made with and without shortening 59

Table 8. Comparison of amylogram readings on bread made with different surfactants 61

Table 9. Loaf volumes and shortening responses in loaf volume and crumb firmness 63

Table 10. Crumb firmness at different storage times 64

Table 11. Correlation coefficients of various variables with crumb firmness 70

Table 12. Best-fitting regression equations.....73

LIST OF FIGURES

Page

Figure 1. A typical bread crumb amylogram showing the definitions of the amylogram characteristics used in this study 15

Figure 2. Schematic diagram of sample preparation for bread crumb amylograph test 21

Figure 3. Amylograph curve of bread flour with repeated cycles 25

Figure 4. Bread crumb amylogram with a repeated cycle ..27

Figure 5. Amylograms of defatted flour and reconstituted flour with a repeated cycle 30

Figure 6. Amylogram of wheat starch enriched with flour lipids with a repeated cycle 32

Figure 7. Amylograms showing that the bump is temperature-dependent 36

Figure 8. A possible explanation of bump formation phenomenon in amylograms 40

Figure 9. Amylograms of wheat starch with different levels of SSL as measured with 40 g starch and 400 ml buffer 44

Figure 10. Crumb amylograms of bread made with 0.5% lipids or various surfactants without shortening 55

Figure 11. Crumb amylograms of bread made with 0.5% lipids or various surfactants and 3% shortening 57

Figure 12. Firming curves of bread made with 0.5% lipids orvarious surfactants without shortening 65

Figure 13. Firming curves of bread made with 0.5% lipids or various surfactants and 3% shortening 68

INTRODUCTION

The amylograph measures the viscosity of a system stirred under controlled temperature. The apparatus has most commonly been used in the studies of various starches and flours. Yasunaga et al (1968) first utilized the amylograph to study the pasting characteristics of bread crumb in order to determine the extent of starch gelatinization during baking and factors that control it. Further work was done by a few other workers (D'Appolonia and MacArthur 1974; Kim and D'Appolonia 1977; Morad and D'Appolonia 1980; Kai 1985; Varriano-Marston et al 1980). It has been found that the amylogram of bread crumb possesses some characteristics which are different from those of starch or flour amylogram. Little explanation has been provided for these differences. It would be certainly desirable to further study bread crumb amylograms to determine the cause of their unique properties.

Yasunaga et al (1968), Morad and D'Appolonia (1980), Kim and D'Appolonia (1977), and Kai (1985) reported that there were possibly relationships between crumb amylogram readings and bread storage. But they did not obtain sufficient data to draw conclusions. They also studied the effects of shortening and certain surfactants on crumb

amylograms to relatively limited extent and further work appears necessary.

Thus, this study was designed to fulfill the following objectives:

1) to elucidate the cause of the unique properties of bread crumb amylograms;

2) to investigate the effects of shortening, surfactants including flour lipids, and storage time on bread crumb amylograms; and

3) to investigate relationships of bread crumb amylogram readings with crumb firmness.

LITERATURE REVIEW

I. Use of Amylograph in Determining Pasting Properties of Bread Crumb

a. Basis of using amylograph in studying bread crumb

The purposes of using the amylograph to test pasting properties of bread crumb were discussed by Yasunaga et al (1968). The focus of this research was on the gelatinization of starch during baking and the retrogradation of starch after baking. Sandstedt et al (1954) examined microscopically the state of starch granules in crumb. Ulmann (1962) examined the effect of baking on the size of starch molecules by chromatography on alumina columns. Yasunaga et al (1968) used the amylograph as another way to examine the extent of starch gelatinization during baking and the effects of various factors which influence starch gelatinization.

Because starch retrogradation plays an important role in bread staling, it has been tempting to relate crumb amylograms to bread staling. The effects of storage times of breads on crumb amylograms have been investigated (Yasunaga et al 1968; D'Appolonia and MacArthur 1974; Kim and D'Appolonia 1977; Morad and D'Appolonia 1980; Kai 1985).

b. The unique features

Yasunaga et al (1968) noticed two characteristics of crumb amylograms that differed from those of flour and starch amylograms. First, the crumb slurry showed a measurable initial viscosity at room temperature. Second, a minor additional peak was observed that was not normally present in flour or starch amylogram. The minor peak appeared at a lower temperature than the major peak, and was particularly prominent when the over-all increase in viscosity was relatively low. The second property was also observed by other researchers (Kim and D'Appolonia 1977; Morad and D'Appolonia 1980; Kai 1985; Varriano-Marston et al 1980).

D'Appolonia and MacArthur (1974), Kim and D'Appolonia (1977) and Morad and D'Appolonia (1980) found a third unique feature when they cooled the slurry after it was heated to and held at 95oC. During the setback at a certain temperature, a sharp increase in viscosity in the bread crumb slurries was noted. This phenomenon was not observed in freeze-dried dough after mixing or fermentation (Kim and D'Appolonia 1974).

There have been no certain explanations for those unique features. Yasunaga et al (1968) assumed that the difference between the initial viscosity and the major peak viscosity was inversely related to the degree of gelatinization during baking. Kim and D'Appolonia (1974)

suggested that the minor peak before the major peak was due to association of starch with other flour constituents during baking. There have been no available explanations as to what causes the unique setback pattern.

c. Sample preparations

There have been two general ways to prepare bread crumb samples for the amylograph test, namely, a soaking-and-dispersing procedure and a lyophilizing-and-grinding procedure.

Yasunaga et al (1968) developed the first procedure, i.e., the soaking-and-dispersing procedure. They examined the effects of various dispersing times and finally selected the following method. A weight of crumb equivalent to 60 g flour (14% mb) is soaked in 300 ml distilled water at room temperature for 1 hr and thereafter dispersed in a Waring Blendor (15 sec at low and 60 sec at high speed) to form a smooth slurry. The slurry is transferred to the amylograph bowl and a further 150 ml distilled water is added. Kai (1985) used the same procedure except that the weight of crumb used was 95 g. Whether or how the moisture content of the bread crumb used for amylograph tests was measured was not mentioned in both reports. However, the moisture content of crumb is very important, especially for the effects of storage times. The change in moisture content will affect the solid content existing in the

amylograph bowl, which in turn affects the viscosity.

D'Appolonia and MacArthur (1974), Morad and D'Appolonia (1980) and Kim and D'Appolonia (1977) used the lyophilizing-and-grinding procedure. After appropriate storage, bread crumb was removed, freeze-dried, and ground on a Wiley mill to pass through a 60-mesh sieve. The sample (60 g db or 55 g) was suspended in 350 ml distilled water by agitating in a Waring Blendor at low speed for 1 min. The suspension was transferred to the amylograph bowl, and the blender was rinsed with 100 ml additional water. This procedure is questionable as to whether the freeze-drying process might exert some extraneous effects on bread crumb properties.

d. Influencing factors

Yasunaga et al (1968) and Kai (1985) took peak viscosity as the major amylograph reading to be considered. On the other hand, D'Appolonia et al (1974), Kim et al (1977) and Morad et al (1980) considered pasting temperature, curve height at the end of holding (95oC) and the curve height at the end of cooling (50oC) as the major readings. Kim et al (1977) also used the curve height at the beginning of the holding (95oC). Morad et al (1980) attempted to relate the peak area in the cooling portion to bread storage times.

The influencing factors of bread crumb amylograms can

be classified into three general groups: baking conditions, baking ingredients, and bread storage conditions and storage time. Morad et al (1980) compared the crumb amylograms of breads baked by the straight dough procedure and continuous procedure and found significant differences. D'Appolonia et al (1974) noted an increase in the peak height of crumb as the broth time in the continuous procedure increased. Yasunaga et al (1968) showed that the amylogram peak height decreased with increases in baking temperature and time. Within a loaf, the amylogram peak height decreased from center to outer portion of bread.

Among baking ingredients, surfactants, sugar (0%-4%), nonfat dry skim milk, and yeast were reported to increase pasting temperature and curve height, whereas water, malt, and damaged starch decreased them (Yasunaga et al 1968; Morad et al 1980).

Yasunaga et al (1968) reported that the initial and peak viscosities of bread crumb amylogram decreased progressively with storage time. This tendency was more pronounced for the bread stored at 4°C than that at 22°C. However, Kai (1985) obtained the opposite result.

II. Bread Staling

Bread staling has long been studied. Yet, its fundamental cause has not been fully understood because the staling phenomenon is extremely complex.

Bechtel et al (1953) defined staling as "a term which indicates decreasing consumer acceptance of bakery products by changes in the crumb other than those resulting from action of spoilage organisms". Actually, bread staling also involves changes in crust, of which crisp texture becomes soft and leathery, and pleasant flavor becomes somewhat bitter (Pyler 1973). Those changes in the crumb include changes in taste and aroma, increases in hardness, opacity, crumbliness, and starch crystallinity, and decreases in absorptive capacity, susceptibility to attack by alpha-amylase, and soluble starch content (Bice and Geddes 1953). Among those changes, the rate of crumb firming has commonly been used as a measurement of bread staling.

Although many factors are involved in bread staling, the starch component present in flour is generally recognized as the major contributor to the bread staling process (D'Appolonia 1985). Lineback (1985) reviewed the the role of starch in bread staling and provided a current explanation of staling. In his opinion, both amylose and amylopectin are involved in staling, but the component of major importance is amylopectin. Retrogradation of amylose is essentially complete after the first day and contributes little to further staling as measured by crumb firming. According to his model, portions of the amylose and amylopectin chains extend beyond the boundary of the granule. As bread stales, these chains can associate or

align (retrograde) with other carbohydrate chains in the interstices between granules and with those protruding in appropriate orientation from the granule boundary when they are in sufficiently close proximity. This leads to structural firming through inter-granular and intra-granular association of amylopectin chains.

Almost every baking ingredient has an influence on bread staling; however, the most effective ingredients used to retard crumb firming or bread staling are the surfactants (D'Appolonia 1985). Surfactants can improve dough properties and increase loaf volume (Tsen 1985), thus reducing crumb firmness (Axford et al 1968). Another way for certain surfactants to reduce crumb firmness is through the formation of an insoluble complex with amylose, which restricts the leaching of amylose from the starch granules. The leached amylose can form a gel between the granules, which contributes to the initial firmness of the bread (Krog 1985; Schoch 1965). Although controversial results have been reported as to whether surfactants reduce the rate of bread crumb firming, virtually all reports showed that surfactants would not increase the firming rate (Kulp and Ponte 1981; Schuster and Adams 1984).

III. Changes of Starch during Amylograph Tests

Starch systems in amylograph tests are usually an excess-water system. Undamaged starch undergoes swelling,

gelatinization, pasting, and retrogradation in an amylograph cycle with heating, holding and cooling.

Although varying considerably, many reports have shown that starch granules take up water and swell slightly before the onset of gelatinization (Banks and Greenwood 1975; Greenwood 1976; Schoch 1965) and swell to a larger extent just before gelatinization (Bowler et al 1980; Radley 1960; Bourne et al 1960). The initial swelling of granules is not usually seen as an increase in viscosity on the amylograph unless a high starch concentration is used (Nishita and Bean 1979) or high-viscosity carboxymethyl cellulose or sodium alginate is added to the suspension (Crossland and Favor 1948).

When the temperature is increased a little higher, 58oC for typical wheat starch, the hydrogen-bonds between molecules are weakened. The granules absorb far more water, swell and begin to lose their birefringence. At 64oC, wheat starch granules lose all their birefringence (Dengate 1984). Afterwards, as the temperature is increased, granules continue to swell, while amylose solubilizes in granules and exudes into the suspension (Jaska 1971). The granular swelling reduces the amount of water available to act as a lubricant between the moving granules (Schoch 1965) while the exudate released from the starch granules forms a mass of connected structure associated with the starch granules (Miller et al 1973), resulting in the sharp

increase of viscosity of the suspension after gelatinization.

After reaching a peak, the viscosity falls because of breakdown of starch structure (Collison 1953). Upon cooling, the randomly oriented molecules of amylose can orient themselves in parallel fashion with large numbers of hydroxyl groups of adjoining chains to form aggregates of low solubility (Dengate 1984). Amylose may also act as a binding material linking intact or fragmented swollen granules (Ott and Hester 1965). As a result, the viscosity increases.

Lipids and most surfactants have been reported to restrict the granule swelling and delay the gelatinization (Ghiasi et al 1982; Medcalf 1968; Eliasson et al 1981). The mechanism is believed to be that lipids and surfactants can adhere on the surface of starch granules as barriers of water uptake and amylose exudation and/or form complexes with amylose within the granules, thus,immobilizing the amylose (Eliasson et al 1981; Schoch 1965; Longley and Miller 1971).

The viscosity change during the amylograph cycle is highly complicated. No completely clear explanations are available at this time.

MATERIALS AND METHODS

I. MATERIALS

a. Flour

The flours used for investigating the causes of unique properties of crumb amylograms were ADM Blend Flour of 10.6% protein (14% mb) obtained from Archer Daniels Midland Co. (Abilene, KS) and a high protein untreated flour obtained from a commercial source. The ADM flour was used for the baking studies.

b. Yeast

Fermipan Instant Yeast (Gist-Brocades N.V., Holland) was used for the baking studies.

c. Shortening

The shortening, Bakeall from Bunge Edible Oil corp. (Kankakee, IL) was made from meat fats and vegetable oils with added butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) to help protect flavor.

d. Surfactants

Sodium stearoyl-2-lactylate (SSL) and distilled

monoglycerides (MG) were obtained from BREDDO Inc. (Kansas City, KS), powdered diacetyl tartartic acid esters of mono- and diglycerides (DATEM) from Hercules Inc. (Wilmington, DE), and sucrose monopalmitate (SMP) from Dai-Ichi Kogyo Seiyaku, Japan.

e. Starch

Unmodified wheat starch from Sigma Chemical Co. (St. Louis, MO) was used.

II. METHODS

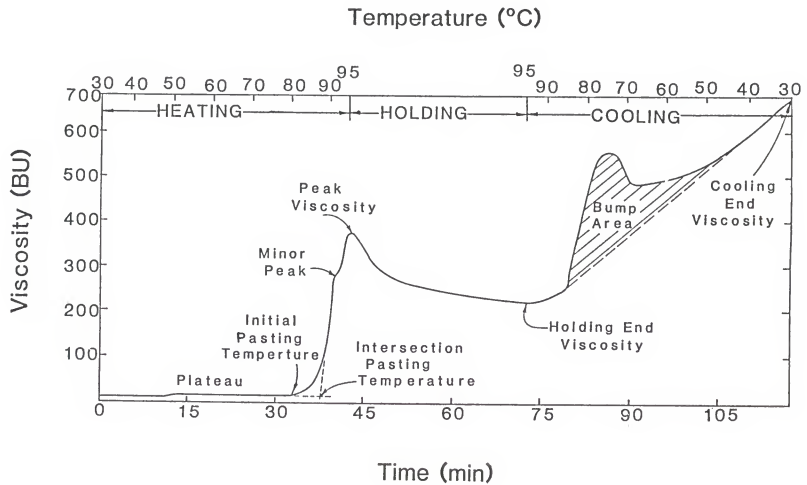
a. Amylograph

The Brabender Viskograph-E (C. W. Brabender Instruments, Inc., South Hackensack, NJ) was used. For flours, the sample preparation was in accordance with AACC Method 22-10 (AACC 1983). For starches, 40 g sample (14% mb) and 400 ml buffer were used. For bread crumb tests, 95 g sample (38% mb) and 450 ml distilled water were used. The samples were heated from 30 to 95°C at a rate of 1.5°C/min, and held at 95°C for 30 min followed by a cooling period which was the reverse of the heating period. In the case of repeated cycles, the holding time was changed after the first cycle to 10 min in order to save time. The viscosity was measured at a torque of 700 cmg and recorded at a chart speed of 20 cm/hr.

b. Amylogram characteristics

Amylogram readings included the peak viscosity, the viscosity at the end of the holding period (holding end viscosity), the viscosity at the end of the cooling period (cooling end viscosity), the bump area as measured with a planimeter and the pasting temperatures. For the temperature range of bumps in the flour amylogram, the starting temperature and the ending temperature of the bumps were also measured. The existence or absence of the plateau before the gelatinization viscosity rise and of the minor peak before the major peak were also considered as amylogram characteristics. The definitions of those characteristics are illustrated in Fig. 1 and described as follows. For the purpose of measurement of bump area, the base line of a bump was considered as the straight line which most smoothly connected the curve beside the bump. Two readings were taken as pasting temperatures: the initial pasting temperature was the temperature at which the viscosity began to rise; and the intersection pasting temperature was the one corresponding with the intersection point of both the relatively horizontal and relatively vertical tangential lines of amylograph curve in the heating period. The starting and the ending temperatures of a bump were corresponding with the intersection points of the two relatively vertical tangential lines of the two sides of the bump with the base line.

Figure 1. A typical bread crumb amylogram showing the definitions of the amylogram characteristics used in this study


Temperature (°C)
30 40 50 60 70 80 90 95
95 90 80 70 60 50 40 30
HEATING
HOLDING
COOLING
Viscosity (BU)
700
600
500
400
300
200
100
Peak Viscosity
Minor Peak
Initial Pasting Temperture
Plateau
Intersection Pasting Temperature
Bump Area
Holding End Viscosity
Cooling End Viscosity
0 15 30 45 60 75 90 105
Time (min)

c. Bread formula

The following formula was used for baking.

Ingredient	Baker's %	Weight (g)
Flour	100	927.5 (14% mb)
Water	Optimum	Optimum
Yeast	1	9.275
Sugar	6	55.65
Salt	2	18.55
NFDM	3	27.825
Shortening	0, 3	0, 27.825
Surfactant	0, 0.5	0, 4.638

The optimum water absorption for baking was 60% based on flour weight for the dough with shortening and 62.5% for the dough without shortening.

d. Baking procedure

The straight dough method was used in baking. All the ingredients were at first placed into the mixing bowl and mixed to optimum dough development. The mixed dough was fermented at 86°C and 85% RH for 2.5 hr, during which the dough was punched at the end of first 2 hr of fermentation. After fermentation, the dough was equally divided into three individual pieces. Each piece was rounded and then rested for 20 min, followed by moulding and panning. The panned dough was proofed at 95°C and 95% RH until the dough height reached 1.5 cm above the pan. The bread was baked at 218.3°C for 25 min. The weight and volume of each loaf were measured immediately after it came out of oven. The loaf

was cooled for 1 hr at room temperature and then wrapped twice with polyethylene bags.

e. Firmness measurement

After the appropriate storage times, loaves were taken out of the polyethylene bag and sliced into one-inch slices. The slices at both ends and in the middle were discarded. The remaining six slices were tested for firmness in gram on a Voland-Stevens-LFRA Texture Analyser (Voland Corp., Hawthorne, NY). The plunger speed was 0.5 mm/sec and the compression distance was 4 mm. Each slice to be tested was put on the analyser with the side closer to the loaf end up so that the moving direction of the plunger was always toward the middle of the loaf along the longitudinal axis. The compression was directed at the center of the slice. The six firmness readings were averaged to give a single firmness value for the loaf.

f. Fat extraction and impregnation

Lipids were extracted from flour with petroleum ether in a Soxhlet for 24 hr. The condensation rate of petroleum ether was one cycle per hour.

To add the extracted flour lipids to wheat starch, the lipids were dissolved in petroleum ether and the wheat starch was mixed thoroughly with the lipid solution. The mixture was dried in a hood overnight. When added to flour,

the lipids were mixed directly with flour in a mortar. The impregnated flour and starch contained 1% and 1.54% lipids (14% mb) respectively.

g. Moisture measurement

The moisture content of flour and starch was measured according to AACC Method 44-15A (AACC 1983) at a temperature of 130oC for 60 min in a convection oven. Since fresh bread crumb contains a high moisture, there is no standard one-stage method for moisture determination of fresh crumb. However, in the present study, it was necessary to know the moisture content of fresh bread crumb before running the amylograph. Therefore, two methods were used for crumb moisture content (Fig. 2). The one-stage method was used for the amylograph test. The oven time was lengthened to 70 min at 130oC in one-stage method in consideration of the high moisture of fresh crumb. The standard two-stage method (AACC Method 44-15A, AACC 1983) was used as a reference of the one-stage method. The moisture of air-dried crumb was determined in the same way as for flour or starch.

h. Storage test procedure

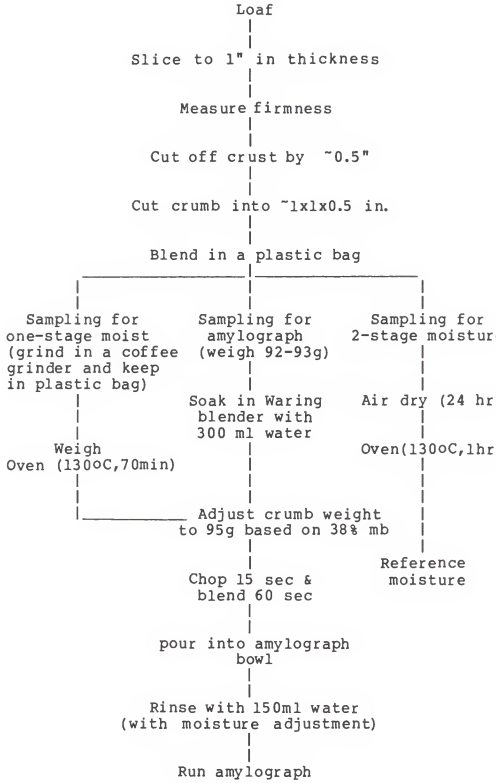
In order to investigate the relationship of bread crumb amylogram readings with crumb firmness and the effects of storage time, shortening and surfactants

including flour lipids on bread crumb amylograms, four surfactants (SSL, SMP, DATEM and MG) and petroleum ether-extracted flour lipids were used to make bread with and without shortening. Two doughs were made for each treatment within each replicate. The firmness of one loaf from each dough was measured after 1, 2 and 5 days of storage at room temperature and crumbs of the two loaves were then used for amylograph studies after each storage time. The procedure for preparation of bread crumb for the amylograph test is shown in Fig. 2.

i. Statistical analysis

The SAS system (Helwig 1978) was used for the statistical analysis of data. LSD (Least Significant Difference) (Ott 1984) was used to determine effects of storage days, shortening and surfactants including flour lipids on the crumb amylograph readings. STEPWISE regression procedure (Ott 1984) was used to find best equations of crumb firmness as a function of other variables.

Figure 2. Schematic diagram of sample preparation for bread crumb amylograph test


Loaf
Slice to 1" in thickness
Measure firmness
Cut off crust by ~0.5"
Cut crumb into ~1x1x0.5 in.
Blend in a plastic bag
Sampling for one-stage moist (grind in a coffee grinder and keep in plastic bag)
Sampling for amylograph (weigh 92-93g)
Sampling for 2-stage moisture
Soak in Waring blender with 300 ml water
Air dry (24 hr)
Weigh
Oven (130oC,70min)
Oven(130oC,1hr)
Adjust crumb weight to 95g based on 38% mb
Reference moisture
Chop 15 sec & blend 60 sec
pour into amylograph bowl
Rinse with 150ml water (with moisture adjustment)
Run amylograph

RESULTS AND DISCUSSION

I. The Cause of the Unique Characteristics of Bread Crumb Amylograms

a. The approach to the problem

Bread crumb is different from flour in at least two aspects. First, many baking ingredients beside flour and water are present in bread crumb. Second, bread has undergone heating during baking and the starch in the crumb has been gelatinized to an extent. It is logical to relate the cause of the unique characteristics of crumb amylograms to those two differences. D'Appolonia et al (1972) investigated the effects of baking ingredients on starch-slurry gelatinization and no similarities to crumb amylograms was found. Therefore, the heating during baking is probably one of the factors responsible for the uniqueness.

If this is true, there are two possibilities of the cause: heating of flour with water only, or along with other ingredients. To test the first possibility, which is simpler than the second, malted bread flour was heated in

the amylograph to 95oC, held for 30 min and cooled to 30oC to imitate the gelatinized flour in bread crumb. Immediately after that, the same slurry was tested in the amylograph for repeated cycles. The holding time was changed to 10 min to save time. The amylogram obtained is shown in Fig. 3. A bump identical to that found in bread crumb amylogram appeared in each cooling period after the first amylograph cycle. An equally-sized bump appeared during each heating period symmetrical with the one appearing during the cooling period. Repeated cycles of bread crumb amylograms showed the same phenomenon after the first cycle (Fig. 4). The temperature at which the sharp decrease in viscosity occurred during the heating period in the second cycle was the same as that where the minor peak occurred before the major peak in the first cycle. This suggested that the minor peak of the bread crumb amylogram was due to the same bump formation phenomenon under a different circumstance. These were considered as evidences indicating that flour alone without other baking ingredients was enough to show the unique features as observed in bread crumb amylograms.

When unmalted bread flour was tested on the amylograph using 100 g sample and 460 ml buffer, the viscosity was very high and no bump was observed (amylogram not shown). This raised a question as to whether the products of amylase action were responsible for the bump formation.

Figure 3. Amylograph curve of bread flour with repeated cycles

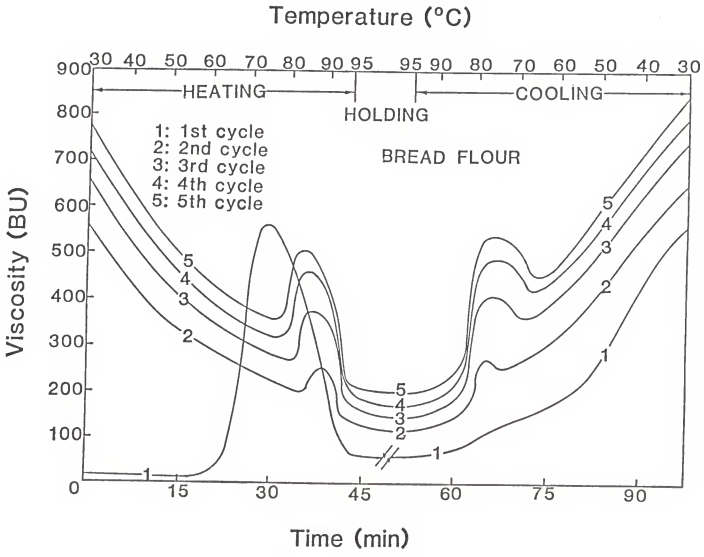
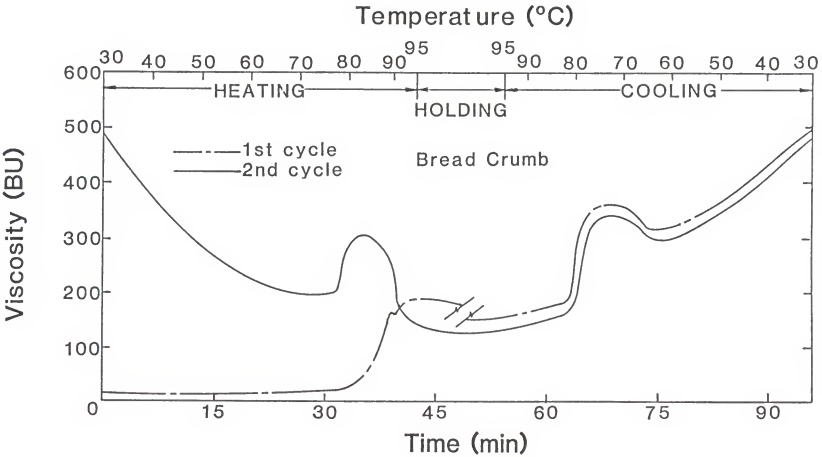

Temperature (°C)
30 40 50 60 70 80 90 95 95 90 80 70 60 50 40 30
HEATING
HOLDING
COOLING
1: 1st cycle
2: 2nd cycle
3: 3rd cycle
4: 4th cycle
5: 5th cycle
BREAD FLOUR
Viscosity (BU)
900
800
700
600
500
400
300
200
100
0
15
30
45
60
75
90
Time (min)

Figure 4. Bread crumb amylogram with a repeated cycle


Temperature (°C)
30 40 50 60 70 80 90 95 95 90 80 70 60 50 40 30
HEATING
HOLDING
COOLING
1st cycle
2nd cycle
Bread Crumb
Viscosity (BU)
600
500
400
300
200
100
0
15 30 45 60 75 90
Time (min)

Dilution of the unmalted flour slurry with water made bumps appear (amylograms not shown), suggesting that the role of malt in bump formation of amylograms was to make the system less viscous, which allowed either the influence on viscosity of certain interactions to show up or the interactions that cause the change in viscosity to occur.

Now, questions remaining to be answered included which component or components of flour were responsible for the unique features. Attention was paid to the major flour components including starch, proteins, lipids, and pentosans.

To determine whether lipids were involved in the bump formation phenomenon, the petroleum ether defatted flour was tested on the amylograph with repeated cycles. The bumps were eliminated, as shown in Fig. 5. However, when the defatted flour was reconstituted with the extracted lipids, the reconstituted flour regained the ability to form bumps in the amylogram (Fig. 5). Those results indicated that lipids were involved in the bump formation, thus, the unique features of bread crumb amylograms.

Wheat starch alone did not exhibit the ability to form bumps in the amylogram (not shown) whereas the addition of wheat flour lipids to wheat starch gave the amylogram (Fig. 6) with the special features as found in both flour and crumb amylograms withrepeated cycles. Therefore, wheat starch and lipids were sufficient and necessary to form the

Figure 5. Amylograms of defatted flour and reconstituted flour with a repeated cycle

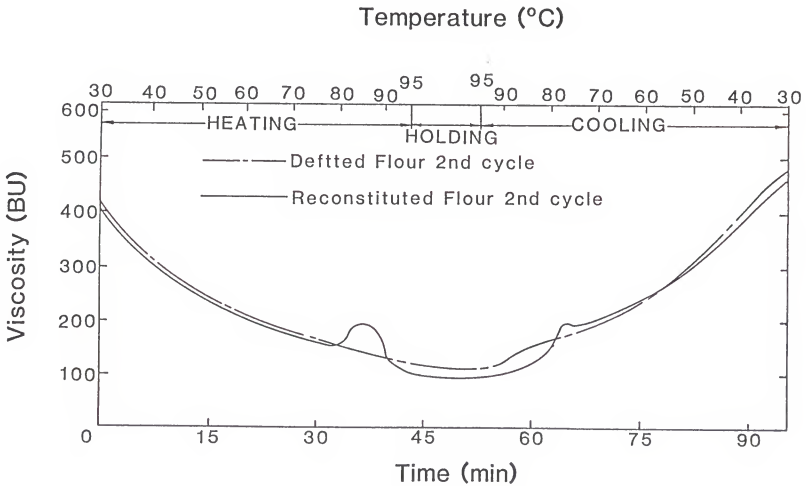
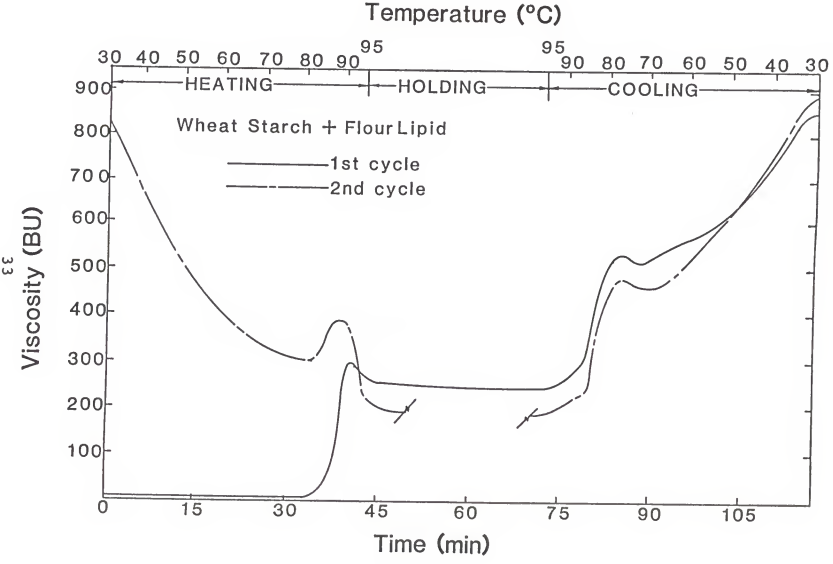

Temperature (°C)
30 40 50 60 70 80 90 95 95 90 80 70 60 50 40 30
HEATING
HOLDING
COOLING
Deftted Flour 2nd cycle
Reconstituted Flour 2nd cycle
Viscosity (BU)
600
500
400
300
200
100
0
15 30 45 60 75 90
Time (min)

Figure 6. Amylogram of wheat starch enriched with flour lipids with a repeated cycle


Temperature (°C)
30 40 50 60 70 80 90 95
95 90 80 70 60 50 40 30
HEATING
HOLDING
COOLING
Wheat Starch + Flour Lipid
1st cycle
2nd cycle
Viscosity (BU)
900
800
700
600
500
400
300
200
100
0 15 30 45 60 75 90 105
Time (min)

bumps in amylograms. Since the bumps could only form after the first cycle in flour amylograms, it is concluded that the interactions of gelatinized starch and lipids were responsible for the unique characteristics of bread crumb amylograms. The minor peak appearing before the major peak was due to the same interactins. It was simply a bump distorted by the further swelling and pasting of the starch, which had been incompletely gelatinized during baking (Varriano-Marston et al 1980).

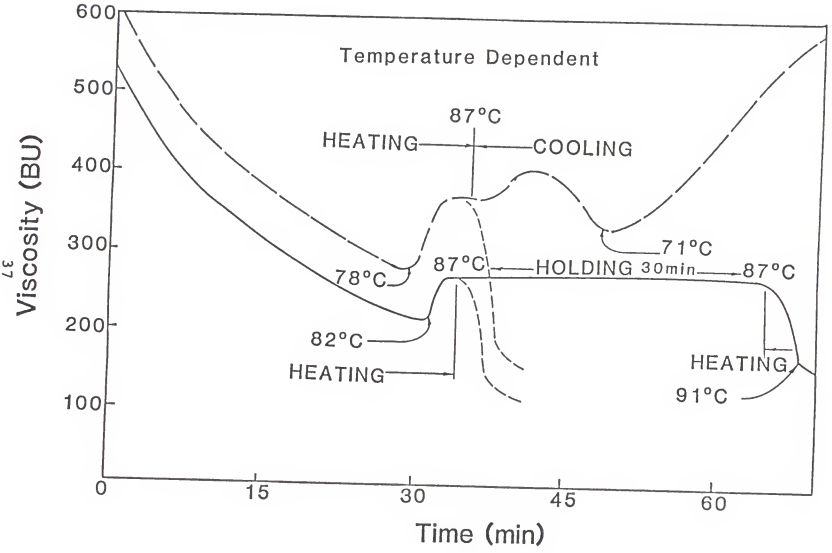
b. Description of the bumps in amylogram

The bumps get bigger with each additional cycle (Fig. 3 and Table 1). The temperature ranges over which bumps occur in the cooling period are about 5 to 7oC less than those in the heating period (Table 1). Within each cycle, the bumps have similar areas and interval of temperature ranges in the heating and cooling periods. The similarity in the interval of temperature ranges raises a question as to whether the viscosity is time-dependent after the initial starting temperature in each cycle. To test this, the temperature was maintained constant for a time when the viscosity reached the top of the bump (Fig. 7). The viscosity did not change during the holding period at the peak temperature of the bump, but decreased as usual when the temperature was changed at a rate of 1.5oC/min after holding. This indicated that the bump formation was

Table 1. Bump Area and Temperature Range of Flour Amylogram with Repeated Cycles

Cycle	Bump Area (in.2)		Temperature Range (oC)	
	Heating	Cooling	Heating	Cooling
2nd	0.48	0.43	82.0-91.0	87.7-79.6
3rd	1.37	1.30	81.0-92.9	88.6-73.9
4th	1.93	1.93	78.7-93.9	88.6-71.6
5th	2.20	2.34	77.7-94.3	89.1-71.1

Figure 7. Amylograms showing that the bump is temperature-dependent


Temperature Dependent
Viscosity (BU)
37
600
500
400
300
200
100
0
15
30
45
60
Time (min)
87°C
HEATING
COOLING
71°C
78°C
87°C
HOLDING 30min
87°C
82°C
HEATING
HEATING
91°C

temperature-dependent. The temperature at which the bump occurs was related to whether the system was being heated or cooled.

When the temperature was decreased, instead of being continuously increased, after the bump reached its top in the heating period, the amylogram bump was as if it were combined with half of the heating bump and half of the cooling bump, as shown by the upper curve in Fig. 7. This suggested that the status of bump-forming materials were the same at the tops of both bumps in the heating period and the cooling period.

c. Discussion of bump formation

Now that we obtained evidence showing that the bump is due to certain interactions of lipids with starch after gelatinization and cooling, it is natural to think of the amylose helix-inclusion complex with lipids.

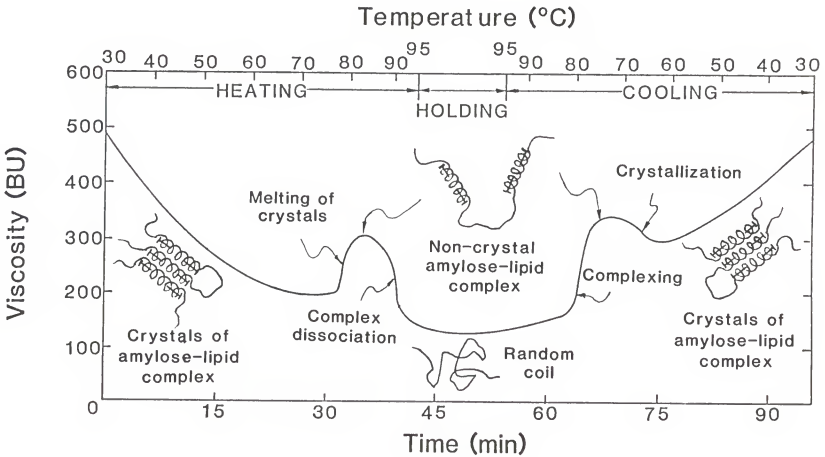
In the presence of complexing agents, the amylose in its solution state can form the crystalline single helical structure (V-amylose state) (Sarko et al 1978). By using Differential Scanning Calorimetry (DSC), many workers (Eliasson et al 1983; Stute et al 1983; Kugimiya and Donovan 1981; Kugimiya et al 1980) have identified amylose-lipid or -surfactant complexing near 100oC or at higher temperature. Kugimiya et al (1980) and Kugimiya and Donovan (1981) also tested wheat starch after cooling and

reheating. The endothermal peak of melting of the amylose-lipids complex reappeared with reheating and even increased in size. This phenomenon is in good accordance with the bump formation in the present study except for the temperature range of the endothermal peak, which was somewhat between 85 and 105°C, higher than those of the bumps in the present study. However, starch concentration is a very important factor that should be considered. When the starch concentration is increased, the order-disorder transition of helical amylose-lipid complexes occurs at a higher temperature (Kugimiya et al 1980). It is highly possible that, in the very dilute system in the present study, the same transition may occur at lower temperature than those by Kugimiya et al (1980) and Kugimiya and Donovan (1981).

Stute et al (1983) concluded that within a temperature range between 70-100°C, a characteristic reorganization of starch-lipid complexes can occur. There can be a transition between the V state and amorphous state at about 100°C.

Based on this information, a possible explanation for the bump formation is described as the followings and illustrated in Fig. 8. At the end of the first cycle, the starch suspension was cooled to 30°C, and the leached amyloses formed single helices with lipids. The lipids stabilized the helical structure. Those helices were packed in crystalline form. At the same time, some amylose might

Figure 8. A possible explanation of bump formation phenomenon in amylograms


Temperature (°C)
30 40 50 60 70 80 90 95
95 90 80 70 60 50 40 30
HEATING
HOLDING
COOLING
Viscosity (BU)
600
500
400
300
200
100
0
Melting of crystals
Crystallization
Non-crystal amylose-lipid complex
Complexing
Crystals of amylose-lipid complex
Complex dissociation
Random coil
Crystals of amylose-lipid complex
15 30 45 60 75 90
Time (min)

connect swollen granules together. As the system was heated in the second cycle, some hydrogen bonds were disrupted, resulting in an eventual decrease in viscosity. At about 80oC, the helical crystals melted and exposed a large number of hydroxyl groups to water molecules. Hydrogen-bonds were formed between them. Thus, the amount of mobile water, i.e., lubricant between swollen granules would have decreased sharply. In addition, the flexible yet rigid starch molecules were easy to be entangled with each other. As a result, the viscosity increased. Shortly after that, the temperature reached the point at which the helical structure could no longer be maintained and the structure turned to the random coil state. This is so called order-disorder transition of helical amylose-lipid complexes. The system at the random coil state would be more fluid and have exhibited a lower viscosity. Thus, a sudden decrease in viscosity was observed.

The cooling period of the second cycle was just a reverse process of the heating cycle except that the temperatures at which the two transitions occurred were lower. This is common in the crystallization and melting processes of polymeric crystals (Mandelkern 1958) as well as some other crystals (Griffin et al 1985).

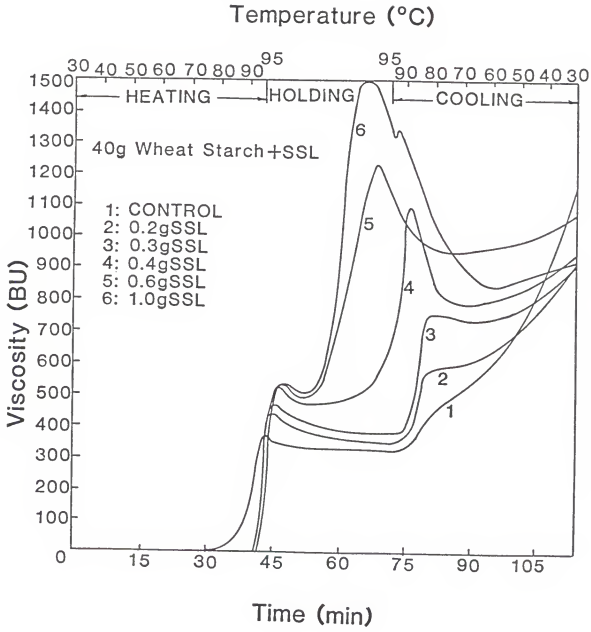
After the second cycle, the process repeated in the same manner except that more soluble starch was available with each additional cycle as pasting continued, resulting

in a higher overall viscosity and a larger bump area. The temperature ranges also extended, the possible mechanism of which might be more complicated.

An interesting but hard-to-explain observation was that there was no bump in the cooling period of the first cycle in the flour amylogram (Fig. 3), suggesting that the state of the system during the first holding period was different from that during the second. Crystals of helical amylose-lipid complexes formed in the first cycle without any indication of viscosity change.

Shortening and surfactants can also play a role in the bump-formation phenomenon. As shown in the next part of this study (Figs. 10 and 11; Tables 2-5), shortening and various surfactants including the native flour lipids, gave distinct shapes and sizes of bumps in the amylograms of bread crumb. In order to see the effects of surfactants on wheat starch amylograph properties in absence of flour lipids, SSL was added to wheat starch at different levels and the amylograms are shown in Fig. 9. In agreement with other authors, the addition of SSL delayed the gelatinization and increased the peak viscosity. However, more dramatic effects were shown during and after the holding period. At lower levels of SSL, bumps with similar temperature range to those found in crumb amylograms were observed. As the level of SSL was increased from 0.2 g to 1 g for 40 g starch and 400 ml buffer, the bump increased in

Figure 9. Amylograms of wheat starch with different levels of SSL as measured with 40 g starch and 400 ml buffer


Temperature (°C)
30 40 50 60 70 80 90 95
95 90 80 70 60 50 40 30
HEATING
HOLDING
COOLING
40g Wheat Starch+SSL
1: CONTROL
2: 0.2gSSL
3: 0.3gSSL
4: 0.4gSSL
5: 0.6gSSL
6: 1.0gSSL
Viscosity (BU)
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
15 30 45 60 75 90 105
Time (min)

size and turned out to be an enormous peak which started in the holding period after the regular peak. Although this phenomenon remains to be further investigated, it suggests that SSL may exert its effect on the bump formation in the bread crumb amylograms through its direct interaction with starch in addition to its interaction with lipids.

II. Results of the Storage Test and Relation of Crumb Amylogram Readings with Crumb Firmness

a. Moisture content of the bread crumb

The moisture contents of bread crumbsare shown in Tables 2 and 3. The correlation coefficient between moisture content values as measured by the two methods was 0.978 at a significance level of 0.0001 indicating that the one-stage method was successful in this study, although the one-stage method generally gave slightly lower value than the two-stage method.

The overall crumb moisture content of bread made with shortening (Table 3) was lower than that of bread made without shortening (Table 2). This was obviously due to the difference in actual baking absorptions. The bread dough with added shortening had 2.5% less water because shortening decreased absorption requirement.

The moisture content of all bread crumb decreased with storage days (Tables 2 and 3). This is in agreement with

Table 2. Crumb Amylogram Readings and Crumb Moisture of Bread Made without Shortening at Different Storage Times a

0.5% Additive	Day	Amylogram Readings b				Moisture c	
		BA	PV	HV	CV	M1	M2
Control	1	0.330	318.5	288.5	582.0	42.5	42.9
	2	0.300	308.5	288.5	566.5	41.7	42.3
	5	0.365	306.5	282.5	571.0	40.0	41.1
Lipid	1	0.375	349.0	313.5	591.5	42.9	42.8
	2	0.385	340.5	313.0	588.5	42.1	41.9
	5	0.370	340.5	315.0	591.0	40.7	40.9
MG	1	0.180	504.5	418.5	814.5	42.8	42.7
	2	0.175	490.5	411.0	794.0	41.5	41.6
	5	0.155	488.5	410.5	818.0	40.1	40.3
DATEM	1	0.295	364.5	325.5	644.5	42.8	42.9
	2	0.345	373.0	334.0	660.5	42.0	42.1
	5	0.285	369.0	333.5	650.5	39.5	39.6
SMP	1	2.405	467.0	323.5	757.5	42.4	42.4
	2	2.405	451.5	325.0	745.5	41.0	41.6
	5	2.460	476.5	344.5	788.5	39.2	39.1
SSL	1	0.115	589.5	410.5	882.5	42.5	42.4
	2	0.100	581.5	402.5	855.0	41.2	42.2
	5	0.115	583.0	408.5	868.0	39.3	39.0

a All data are the average of two replicates, with no duplicate for amylogram readings but at least three duplicates for moistures in each replicate.

b BA=Bump Area (in.2),
PV=Peak Viscocity (BU),
HV=Holding End Viscocity (BU),
CV=Cooling End Viscocity (BU).

c M1=Moisture (%) measured with one-stage method,
M2=Moisture (%) measured with two-stage method.

Table 3. Crumb Amylogram Readings and Crumb Moisture of Bread Made with Shortening at Different Storage Times a

0.5% Additive	Day	Amylogram Readings b				Moisture c	
		BA	PV	HV	CV	M1	M2
Control	1	1.520	194.5	158.5	509.0	40.3	40.5
	2	1.550	198.5	164.0	519.0	39.5	39.5
	5	1.555	192.5	173.5	544.0	37.5	37.6
Lipid	1	2.100	282.5	173.0	536.0	40.6	40.7
	2	2.090	275.5	172.5	536.0	39.7	40.1
	5	2.070	283.5	175.0	537.5	38.3	38.2
MG	1	3.115	386.5	347.5	701.0	40.4	40.9
	2	3.125	398.5	358.0	724.0	39.6	40.1
	5	3.220	394.5	361.0	734.0	37.2	38.0
DATEM	1	2.665	253.5	192.0	585.0	40.9	41.2
	2	2.735	285.5	207.5	633.0	39.7	40.1
	5	2.690	259.5	193.0	586.5	37.6	37.7
SMP	1	3.745	327.5	231.0	685.0	40.4	40.4
	2	3.690	330.5	239.0	689.0	39.9	40.2
	5	3.840	340.0	244.0	714.5	37.9	37.5
SSL	1	1.740	458.0	279.5	793.0	40.7	40.6
	2	1.745	456.5	279.5	796.0	39.4	39.8
	5	1.625	454.0	275.0	787.5	37.6	38.0

a All data are the average of two replicates, with no duplicate for amylogram readings but at least three duplicates for moistures in each replicate.

b BA=Bump Area (in.2),
PV=Peak Viscocity (BU),
HV=Holding End Viscocity (BU),
CV=Cooling End Viscocity (BU).

c M1=Moisture (%) measured with one-stage method,
M2=Moisture (%) measured with two-stage method.

other workers (Yasunaga et al 1968; Kai 1985; Pisesookbunterng and D'Appolonia 1983). This decrease was mainly caused by redistribution of water within the loaf, i.e., a migration of moisture from the crumb to the crust, which is one of the phenomena of bread staling.

For the bread without shortening, DATEM, SMP and SSL enhanced the decrease of crumb moisture with storage time compared with the control (Table 2). This is also in agreement with Pisesookbunterng and D'Appolonia (1983). They postulated that surfactants prevented starch from taking up water released from gluten during bread aging, thus allowing the water migration to the crust. The phenomenon was not as obvious for the bread made with shortening (Table 3).

b. Effects of storage times on crumb amylogram readings

The effects of storage times of breads are shown on the amylogram bump area and viscosity readings (Tables 2 and 3) and on the pasting temperatures and the status of minor peak as well as the plateau before the onset of the gelatinization viscosity rise (Tables 4 and 5).

The statistical analysis using LSD (Least Significant Difference) showed no significant differences at 0.05 level between amylograph readings of different days except for the initial pasting temperature, which decreased slightly with storage days (Table 6). This was not in agreement with

Table 4. Pasting Temperatures and Other Characteristics of Amylograms of Bread Crumb without Shortening

0.5% Surf.	Day	Replicate 1				Replicate 2			
		Pl	MP	Templ	Temp2	Pl	MP	Templ	Temp2
Control	1	Y	N	74.1	84.7	Y	N	72.7	85.0
	2	Y	N	72.7	84.1	Y	N	74.1	84.1
	5	Y	N	72.7	84.7	Y	N	71.3	84.1
SSL	1	N	N	83.0	91.7	N	N	81.9	91.7
	2	N	N	80.8	91.7	N	N	81.9	91.7
	5	N	N	80.5	91.7	N	N	81.6	91.7
DATEM	1	S	N	76.6	87.5	S	N	77.4	87.5
	2	Y	N	76.6	86.4	Y	N	77.4	87.2
	5	Y	N	74.4	86.6	Y	N	76.6	86.7
MG	1	N	N	82.7	91.4	N	N	83.6	91.9
	2	N	N	82.4	91.7	N	N	83.0	91.9
	5	N	N	80.8	91.1	N	N	82.4	92.5
Lipid	1	Y	N	73.2	85.5	S	N	74.1	85.2
	2	Y	N	74.1	85.2	Y	N	75.2	85.8
	5	Y	N	75.2	85.5	Y	N	73.2	85.2
SMP	1	N	N	79.7	89.1	N	N	79.7	90.0
	2	Y	N	78.3	89.4	Y	N	78.3	89.4
	5	Y	N	76.9	91.0	Y	N	77.7	89.4

Note: Pl=Plateau, MP=Minor peak, Y=Yes, S=Slight, N=No, Templ=Inititial pasting temperature, Temp2=Intersection pasting temperature.

Table 5. Pasting Temperatures and Other Characteristics of Amylograms of Bread Crumb with Shortening

0.5% Surf.	Day	Replicate 1				Replicate 2			
		Pl	MP	Temp1	Temp2	Pl	MP	Temp1	Temp2
Control	1	Y	Y	74.4	84.1	Y	Y	74.9	84.7
	2	Y	Y	74.6	84.4	Y	Y	75.2	85.0
	5	Y	Y	72.4	84.1	Y	Y	71.8	84.7
SSL	1	N	N	81.3	91.2	N	N	83.0	90.5
	2	N	N	82.4	91.1	N	N	81.6	90.8
	5	N	N	82.4	91.1	N	N	82.4	91.0
DATEM	1	N	S	77.1	83.8	N	S	76.9	85.2
	2	S	S	75.8	83.3	Y	S	73.0	85.5
	5	Y	S	75.5	85.0	Y	S	73.8	85.2
MG	1	N	N	83.0	90.8	N	N	83.6	91.5
	2	N	N	82.8	90.8	N	N	84.7	91.4
	5	N	N	82.4	91.4	N	N	83.6	91.4
Lipid	1	Y	N	74.9	84.4	N	N	75.2	85.2
	2	Y	N	75.2	84.1	Y	N	74.4	85.7
	5	Y	N	72.4	83.8	Y	N	72.7	84.4
SMP	1	N	Y	77.7	87.2	N	Y	79.7	87.2
	2	S	Y	77.7	86.4	S	Y	80.8	87.5
	5	Y	Y	76.9	86.9	Y	Y	79.7	88.0

Note: Pl=Plateau, MP=Minor peak, Y=Yes, S=Slight, N=No,
Temp1=Initial pasting temperature,
Temp2=Intersection pasting temperature.

Table 6. Comparison of Bread Amylogram Readings among Storage Days

Day	Bump Area	Peak Viscosity	Holding End Visc.	Cooling End Visc.	Templ	Temp2
1	1.54 a	374.6 a	288.5 a	673.4 a	78.4 a	87.7 a
2	1.55 a	374.2 a	291.2 a	675.6 a	78.0 a	87.8 a
5	1.56 a	374.0 a	293.0 a	682.6 a	77.1 b	87.8 a

The same letter in each reading represents means which are not significantly different at 0.05 level.
The bump area is in square inches, viscosities in BU and temperatures in oC. Templ=Initial pasting temperature. Temp2=Intersection pasting temperature.

the contradictory results reported by previous workers, who either found decreases in viscosity with storage times (Yasunaga et al 1968) or found increases in viscosity with storage times (Kai 1985). Morad et al (1980) attempted to relate bump area to storage time but did not make a firm conclusion. No significant difference between days was found with bump area in the present study (Table 6).

The only reading which showed a significant difference was the initial pasting temperature which was the temperature at which the viscosity began to rise (Table 6). There was a general tendency towards decreased initial pasting temperature with storage days. An interesting phenomenon was that, in the heating period of the first cycle of bread crumb amylogram, some crumb gave a plateau before the viscosity rise upon gelatinization. The existence of the plateau depended on the type of additives in the bread formulation, e.g. control breads (both with and without shortening) and breads containing additional flour lipids showed plateaus whereas breads containing SSL or MG did not (Tables 4 and 5). In the case of DATEM and SMP, the existence and/or extent of the plateau changed with storage times: there was a definite increasing tendency in plateau size with storage time. This might affect the reading of the initial pasting temperature, which was quite subjective itself. The determination of intersection pasting temperature was not as subjective and

was much less influenced by the plateau. It did not show a significant change over storage time.

The plateau before the sudden increase of viscosity due to gelatinization is considered to be caused by the swelling of starch granules. The increase in plateau size with storage times in bread crumb amylograms suggests that bread staling might influence the further swelling behavior of the incompletely gelatinized starches in crumb in the amylograph. This can be further examined by using carboxymethyl cellulose or sodium alginate.

The increasing tendency of the plateau with storage times and the insignificant effects of storage time on all the amylogram readings other than the initial pasting temperature indicate that after the crumb slurry reached a high temperature, either the staling effects were lost, or the effects were so small that they could not be precisely detected by the amylograph procedure.

c. Effects of treatments on crumb amylogram readings

Figures 10 and 11 present amylograph curves of bread crumbs made with lipids and various surfactants with and without shortening. The curve shape and height differed depending on the additives in bread formulation.

Analysis of variance showed that shortening caused a significant difference in bread crumb amylogram readings, except for the initial pasting temperature (Table 7). Bread

Figure 10. Crumb amylograms of bread made with 0.5% lipids or various surfactants without shortening

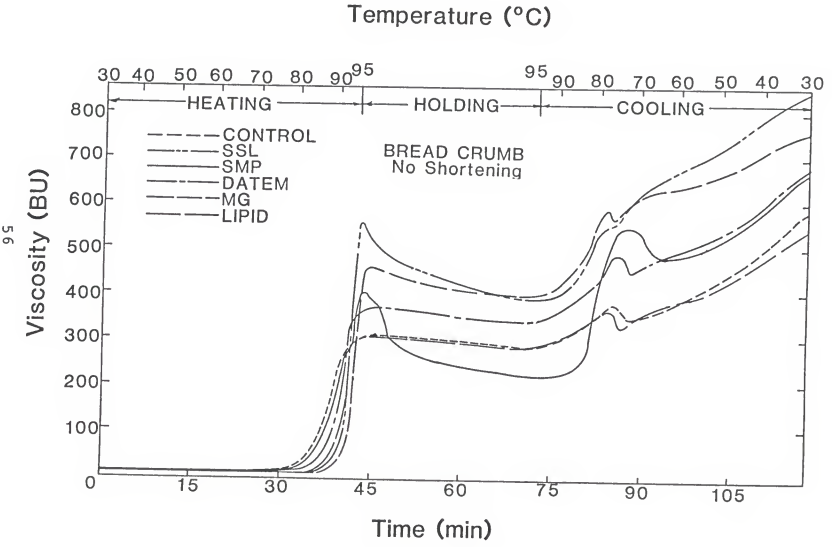

Temperature (°C)
30 40 50 60 70 80 90 95
95 90 80 70 60 50 40 30
HEATING
HOLDING
COOLING
CONTROL
SSL
SMP
DATEM
MG
LIPID
BREAD CRUMB
No Shortening
Viscosity (BU)
800
700
600
500
400
300
200
100
0
15
30
45
60
75
90
105
Time (min)

Figure 11. Crumb amylograms of bread made with 0.5% lipids or various surfactants and 3% shortening

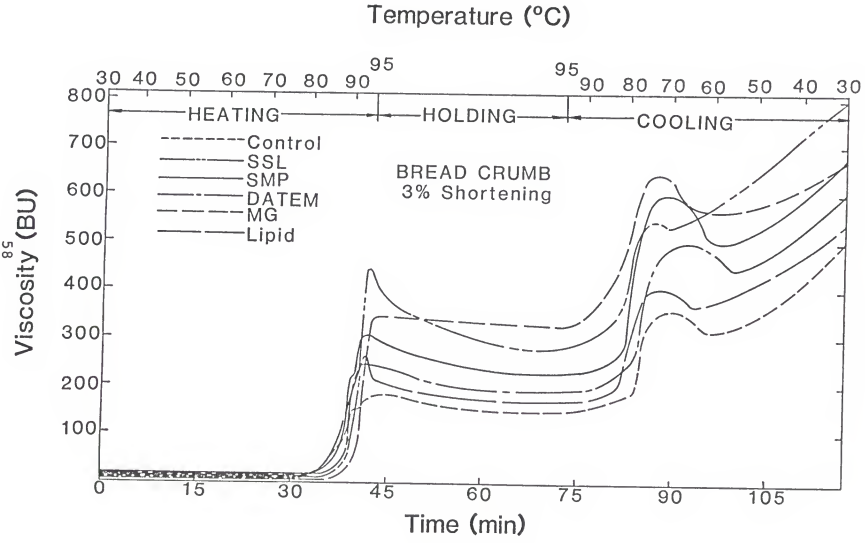

Temperature (°C)
30 40 50 60 70 80 90 95
95 90 80 70 60 50 40 30
HEATING
HOLDING
COOLING
Control
SSL
SMP
DATEM
MG
Lipid
BREAD CRUMB
3% Shortening
Viscosity (BU)
800
700
600
500
400
300
200
100
0
15
30
45
60
75
90
105
Time (min)

Table 7. Comparison of Amylogram Readings on Bread Made with and without Shortening

TRT	Bump Area	Peak Visc.	Holding End Visc.	Cooling End Visc.	Templ	Temp2
3% Shtng	2.49 a	320.6 b	234.6 b	645.0 b	77.9 a	87.2 b
No Shtng	0.62 b	427.9 a	247.1 a	709.4 a	77.7 a	88.3 a

The same letter in each reading represents means which are not significantly different at 0.05 level.
The bump area is in square inches, viscosities in BU and temperatures in °C. Templ=Initial pasting temperature. Temp2=Intersection pasting temperature.

crumb with 3% shortening gave lower viscosities, much bigger bump and lower intersection pasting temperature (Fig. 11) than bread without shortening (Fig. 10). When shortening was not added, no minor peak appeared before the major peak (Table 4). If shortening was added, the appearance of the minor peak depended on the surfactant added: the control bread and breads containing DATEM and SMP showed minor peaks while those containing SSL, MG, and flour lipids did not show them (Table 5).

All the amylogram readings were affected significantly by different treatments in terms of lipids and surfactants (alpha = 0.05), as indicated by the LSD analysis results shown in Table 8. Overall, those treatments which led to higher values in one reading would also have higher values in other readings and vice versa. In general, the treatment with higher viscosities had bigger bumps and higher pasting temperatures. The biggest exception of this rule was with SSL: the bump areas of the SSL-crumb amylograms were the smallest of the six treatments while the SSL-crumb gave both high viscosities and pasting temperatures. Another point which may be worthwhile to mention is that SMP gave bump areas which were outstandingly larger than those yielded by other treatments. The mechanism of SMP in dough strengthening and crumb softening may be different from the other surfactants used.

Analysis of variance procedure showed that, for every

Table 8. Comparison of Amylogram Readings on Bread Made with Different Surfactants

0.5% Surf.	Bump Area	Peak Visc.	Holding End Visc.	Cooling End Visc.	Temp1	Temp2
SSL	0.91 d	520.4 a	342.6 b	830.3 a	81.9 b	91.3 a
SMP	3.09 a	398.8 c	284.5 c	730.0 c	78.6 c	88.5 b
MG	1.66 b	443.8 b	384.4 a	764.2 b	82.9 a	91.4 a
DATEM	1.50 b	317.5 d	264.3 cd	626.7 d	75.9 d	85.8 c
Lipid	1.23 c	311.9 d	243.7 ed	563.5 e	74.2 e	85.0 d
Control	0.94 d	253.5 e	225.9 e	548.6 e	73.4 e	84.5 e

The same letter in each reading represents means which are not significantly different at 0.05 level.
The bump area is in square inches, viscosities in BU and temperatures in oC. Temp1=Initial pasting temperature. Temp2=Intersection pasting temperature.

amylogram reading, interaction between surfactants and shortening existed at a significance level of alpha=0.05. No significant interaction of days with either surfactants or shortening was found.

d. Effects of shortening, lipids and surfactants on loaf volume and crumb firmness

Table 9 shows the average loaf volumes of bread made with flour lipids and various surfactants with and without shortening. Also shown is shortening responses in loaf volume of lipids and various surfactants. When shortening was not added, surfactants improved loaf volume greatly, most with SSL followed by SMP, DATEM and MG. When 3% shortening was added in the baking formula, the loaf volume improvement by surfactants was relatively small, probably because the control bread was already large enough. This was also the reason why the shortening response was relatively less for those containing surfactants than the control breads (Table 9). The result was in agreement of other workers (Tsen and Hoover 1971; Junge and Hoseney 1981).

Table 10 shows crumb firmness values of breads made with different treatments after storage times of 1, 2 and 5 days. Without shortening, surfactants produced substantial improvement in reducing crumb firmness, with SSL and SMP giving the softest crumb (Fig. 12). Flour lipids lowered

Table 9. Loaf Volumes and Shortening Responses[a] in Loaf Volume and Crumb Firmness

0.5% Surf.	Loaf Volume (cc) 0% Shortening	Loaf Volume (cc) 3% Shortening	Shortening Responses Loaf Volume (cc)	Firmness (g) 1 day	Firmness (g) 2 day	Firmness (g) 5 day
None	2313	2874	561	-66	-71	-137
Lipid	2383	2866	483	-25	-60	-97
MG	2568	2899	331	-12	-5	-18
DATEM	2768	2883	115	-7	8	-6
SMP	2825	2961	136	33	55	40
SSL	2874	3020	146	19	31	-7

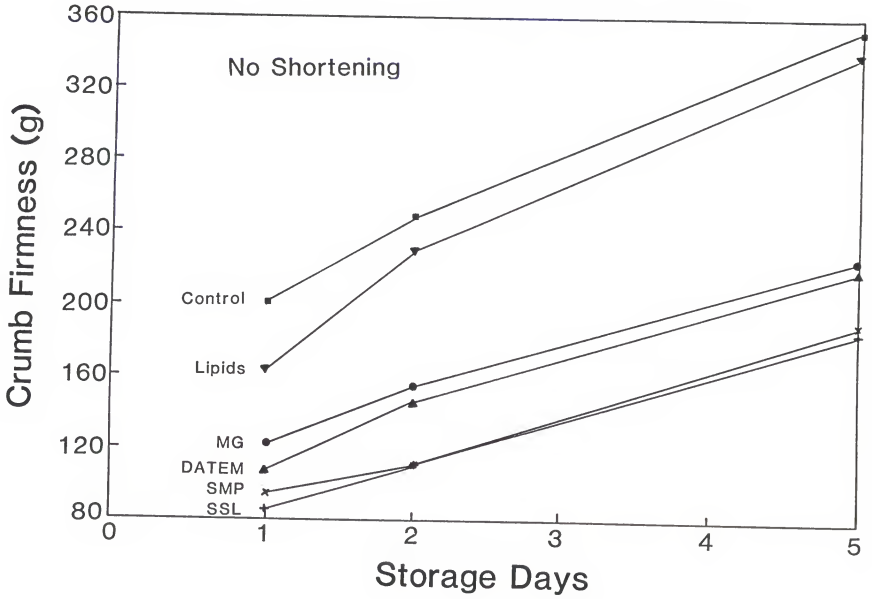
a Shortening Response
= Value with shortening - Value without shortening.

Table 10. Crumb Firmness[a] at Different Storage Times

0.5% Additive	No Shortening			3% Shortening		
	1 Day	2 Day	5 Day	1 Day	2 Day	5 Day
None	200.5	248.2	353.0	134.8	176.8	216.4
Lipid	162.9	228.9	338.8	137.5	168.9	241.9
MG	121.8	154.3	224.3	109.6	149.4	206.8
DATEM	107.1	145.7	218.4	100.3	153.7	212.2
SMP	94.8	111.1	188.6	127.5	166.5	228.7
SSL	84.6	110.8	185.3	104.0	141.7	178.2

[a] Unit: gram.

Figure 12. Firming curves of bread made with 0.5% lipids or various surfactants without shortening


No Shortening
Crumb Firmness (g)
360
320
280
240
200
160
120
80
0
1
2
3
4
5
Storage Days
Control
Lipids
MG
DATEM
SMP
SSL

crumb firmness to a small extent. The firming rates, as indicated by the curve slope, of breads containing surfactants were smaller than those containing none or flour lipids.

When 3% shortening was used in the bread formula, the reduction of crumb firmness by surfactants (Fig. 13) was not as substantial as bread without shortening (Fig. 12), mainly because shortening alone without surfactants reduced crumb firmness greatly compared to bread without shortening or surfactants. SSL was the best in reducing firmness and retaining softness of bread with shortening added, followed by DATEM and MG. SMP showed reduction of firmness in the first two days of storage only. Lipids showed no improving effect on crumb firmness and increased crumb firmness at the fifth day of storage more than the control bread (Fig. 13).

Table 9 indicates that addition of shortening in the presence of SMP or SSL did not exert further improvement on crumb softness, but rather detrimental effects. However, the addition of shortening was beneficial in terms of crumb softness for the control breads and breads containing flour lipids and MG, where the original volume and softness without shortening were poor.

e. Relation of crumb amylogram readings to crumb firmness

Table 11 shows correlation coefficients between crumb

Figure 13. Firming curves of bread made with 0.5% lipids or various surfactants and 3% shortening

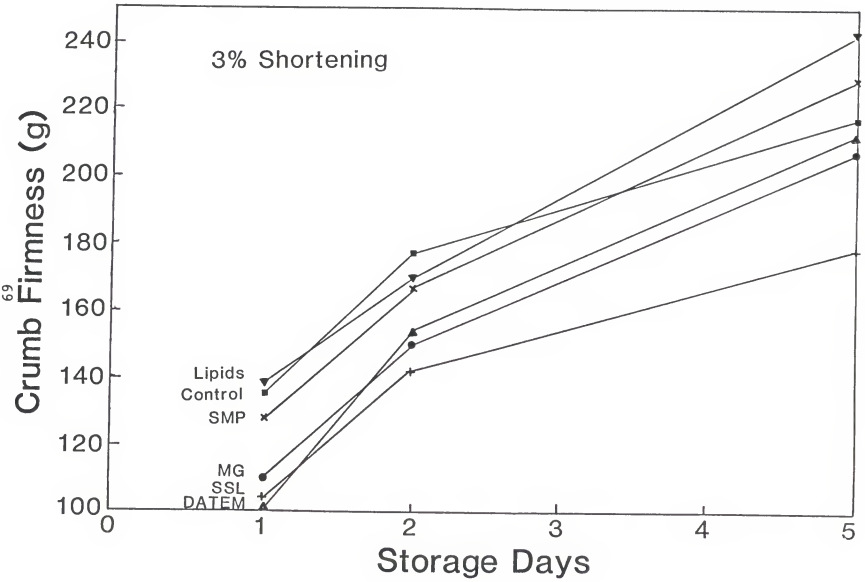

3% Shortening
Crumb Firmness (g)
240
220
200
180
160
140
120
100
0
1
2
3
4
5
Storage Days
Lipids
Control
SMP
MG
SSL
DATEM

Table 11. Correlation Coefficiants of Various Variables with Crumb Firmness

Variable a	Correlation Coefficients with Firmness b		
	No Shortening	3% Shortening	Both
Day	0.678**	0.908**	0.723**
Loaf Volume	-0.692**	-0.208	-0.541**
Moisture	-0.478**	-0.879**	-0.359**
Bump Area	-0.235	0.035	-0.198
Peak Viscosity	-0.593**	-0.229	-0.318*
Hold. End Visc.	-0.468*	-0.181	-0.117
Cool. End Visc.	-0.592**	-0.203	-0.385**
Temp1	-0.621**	-0.331**	-0.486**
Temp2	-0.583**	-0.216	-0.393**

a Hold.=Holding, Cool.=Cooling, Visc.=Viscosity.
Temp1=Initial pasting temperature.
Temp2=Intersection pasting temperatutre.

b ** Significant at 0.05 level.
* Significant at 0.1 level.

firmness and amylogram readings, storage days, loaf volumes, and crumb moisture contents of breads made with or without 3% shortening. Crumb firmness was most highly related to storage days as one would expect it. It was inversely correlated to nearly all other variables. When shortening was in the system, loaf volume was not as important parameter in relation to the crumb firmness as in the no-shortening system, because the range in loaf volume was smaller (2866-3020 cc) for the shortening system than that for the no-shortening system (2313-2874 cc) (Table 9), thus, shielding the effects of loaf volumes on the firmness of breads with shortening added. Moisture content was significantly correlated with crumb firmness of breads for all three systems (Table 11). This was probably because crumb moisture decreased with time concomitantly as firmness increased. The correlation coefficient of bump area with crumb firmness was not significant at the 0.1 level. All other amylogram readings were significantly correlated with crumb firmness of the no-shortening breads. However, for the shortening-bread series, only the initial pasting temperature was significantly correlated with crumb firmness. If both systems were considered together, all the variables except bump area and holding end viscosity showed significant correlations. The significance level was 0.05 except for the peak viscosity (0.1 level).

The same variables used for the correlation

coefficients, excluding pasting temperatures, were used in STEPWISE procedure to find best-fitting regression equations for crumb firmness to determine multiple factors related to crumb firmness. The no-shortening system, shortening system, and combined system were computed separately to obtain best-fitting regression equations for each system. The obtained equations are shown in Table 12. Every variable in the equations was significant at 0.05 level based on T-test. The R-square values, are fairly high (0.888-0.958), indicating these equations are well fitting (Table 12). Comparison of firmness values predicted by these equations with the actual values proved that these equations were good.

Storage days were included for all three equations. This was expected since a major problem of bread staling is progressive firming of bread upon storage. Loaf volume was also included in the best-fitting equations for the no-shortening and combined systems: the larger the loaf volume of bread, the lower the firmness would be. This is reasonable, because the density of bread is smaller for bread with larger volume, and there would be less material resisting the motion of the plunger of the texture analyser. Loaf volume was not included in the shortening system equation because the loaf volumes of breads with different additives in the presence of 3% shortening were similar, thus, diminishing the importance of loaf volume in

Table 12. Best-fitting Regression Equations

No Shortening:

$F = 745.9 + 30.33\ D - 0.2629\ H - 0.2111\ V \quad (R2=0.958)$

With Shortening:

$F = 172.3 + 22.82\ D - 0.1070\ C \quad (R2=0.888)$

Combined:

$F = 664.0 + 26.55\ D - 0.2326\ H - 0.1784\ V \quad (R2=0.901)$

F------Firmness (g)
D------Storage day
V------Loaf volume (cc)
H------Viscosity (BU) at the end of the holding stage
C------Viscosity (BU) at the end of the cooling stage

determining crumb firmness. One amylogram viscosity reading was also included in each best-fitting equation: with the no-shortening and combined systems contained the viscosity at the end of the holding period and the shortening system contained the viscosity at the end of the cooling period. Higher viscosities accompanied lower firmness.

When the STEPWISE procedure was run without amylogram variables, the R-square values decreased significantly, confirming that amylograph properties of bread crumb were certainly related to crumb firmness in addition to storage days and loaf volume. Since loaf volume has indicated most of the dough-strengthening effect of surfactants, amylograph properties of bread crumb should reveal the crumb-softening effects of surfactants through showing their effect on the extent of starch gelatinization in bread crumb, and starch-lipid and -surfactant interactions. Surfactants restricted starch gelatinization during baking, and also delayed the further swelling of the incompletely gelatinized starch in bread crumb in the amylograph. Therefore, the viscosities of crumb amylogram of bread with surfactants were higher than those of bread without surfactants. This would partly explain the negative correlations of crumb firmness with the viscosity terms.

CONCLUSIONS

1. The unique features of crumb amylograms, i.e.,the minor peak before the major peak and the bump during the setback were caused by the interactions of starch with lipids, both native in flour and added in the formula. This interaction was temperature-dependent and reversible.

2. The amylograms of bread crumbs were generally insignificantly changed with storage times of the loaves, but the extent of plateau before the onset of the viscosity rise, if existing, showed an increasing tendency with storage times and the initial pasting temperature showed a decreasing tendency upon storage.

3. Crumb moisture content was related inversely with storage time; this inverse relationship was accelerated for no-shortening breads containing SSL, SMP, or DATEM.

4. The crumb amylograms of loaves made with various surfactants were significantly different and related to crumb firmness. The addition of shortening in bread formula made significant differences in amylogram properties except for the initial pasting temperature. However, shortening in

formula did not provide further beneficial effects on crumb softness of breads containing certain surfactants at the 0.5% level. It may be due to the shartening-replacing effects of certain surfactants that could produce satisfactory breads with acceptable volume and crumb softness.

5. In addition to storage days and loaf volumes, crumb amylogram properties were necessary variables to be included in regression equations for predicting the crumb firmness values. The viscosity at the end of the cooling period and the viscosity at the end of the holding period were the best amylogram variables to be used in the regression equations.

ACKNOLEDGMENT

The author wishes to express his sincere appreciation to Professor Joseph G. Ponte, Jr. and Dr. Okkyung Kim Chung for their valuable guidance and advices during the course of this study. Deep gratitude is also due to Dr. Paul A. Seib, Dr. R. Carl Hoseney and Mr. Karel Kulp for their suggestions on the research.

The author is also grateful to Huifen He and Chron-si Lai for their encouragement and help.

REFERENCES

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC. 8th ed. Methods 22-10, final approval 5-5-60, revised 10-27-82, and 44-15A, final approval 10-30-75, revised 10-28-81. The Association: St. Paul, MN.

AXFORD, D., COLWELL, K., CORNFORD, S., and ELTON, G. 1968. Effect of loaf specific volume on the rate and extent of staling in bread. J. Sci. Food Agric. 19: 95.

BANKS, W., and GREENWOOD, C. T. 1975. Page 342 in: Starch and Its Components. Edinburgh University Press: Edinburgh.

BECHTEL, W. G., MEISNER, D. F., and BRADLEY, W. B. 1953. Effect of the crust on the staling of bread. Cereal Chem. 30: 160.

BICE, C. W. and GEDDES, W. F. 1953. The role of starch in bread staling. Page 202 in: Starch and Its Derivatives. 3rd ed. J. A. Radley, ed. Chapman and Hall: London.

BOURNE, E. J., TIFFIN, A. I., and WEIGEL, H. 1960. Interaction of starch with sucrose stearates and other antistaling agents. J. Sci. Food Agric. 11: 101.

BOWLER, P., WILLIAMS, M. R., and ANGOLD, R. E. 1980. A hypothesis for the morphological changes which occur on heating lenticular wheat starch in wheat. Staerke 32:186.

COLLISON, R. 1953. Swelling and gelation of starch. Page 168 in: Starch and Its Derivatives. 3rd ed. J. A. Radley, ed. Chapman and Hall: London.

CROSSLAND, L. B., and FAVOR, H. H. 1948. Starch gelatinization studies. II. A method for showing the stages in swelling of starch during heating in the

amylograph. Cereal Chem. 25: 213.

D'APPOLONIA, B. L., and MacARTHUR, L. A. 1974. Effect of ingredients on continuous bread-crumb pasting characteristics. Cereal Chem. 51: 195.

D'APPOLONIA, B. L. 1984. Factors for consideration in bread staling. Page T-1 in: International Symposium on Advances in Baking Science and Technology. Dept. of Grain Science and industry, Kansas State University: Manhattan, KS.

DENGATE, H. N. 1984. Swelling, pasting and gelling of wheat starch. Page 49 in: Advances in Cereal Science and Technology. Vol. VI. Y. Pomeranz, ed., Am. Assoc. Cereal Chem.: St. Paul, MN.

ELIASSON, A.-C., CARLSON, T. L.-G., LARSSON, K., and MIEZIS, Y. 1981. Some effects of starch lipids on the thermal and rheological properties of wheat starch. Staerke 33: 130.

ELIASSON, A.-C.,and KARLSSON, R. 1983. Gelatinization properties of different size classes of wheat starch granules measured with differential scanning calorimetry. Staerke 35: 130.

GHIASI, K., HOSENEY, R. C., and VARRIANO-MARSTON, E. 1982. Gelatinization of wheat starch. I. Excess-water systems. Cereal Chem. 59: 81.

GREENWOOD, C. T. 1976. Starch. Page 119 in: Advances in Cereal Science and Technology. Vol. I. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

GRIFFIN, A. C., VAIDYA, S.R., and STEELE, M. L. 1985. Liquid crystalline polymers: Phenomenological and synthetic aspects. Page 1 in: Polymeric Liquid Crystals. A. Blumstein, ed. Plenum Press: New York and London.

HELWIG, J. T. 1978. ed. SAS Introductory Guide. 3rd ed. SAS Institute Inc.: Cary, NC.

JASKA, E. 1971. Starch gelatinization as detected by proton magnetic resonance. Cereal Chem. 48: 437.

JUNGE, R. C. and HOSENEY, R. C. 1981. A mechanism by which shortening and certain surfactants improve loaf volume in bread. Cereal Chem. 58: 408.

KAI, T. 1985. Comparison of residual sugar and firming characteristics of white pan breads made by sponge dough and short-time dough processes. M.S. thesis, Kansas State University: Manhattan, KS.

KIM, S. K., and D'APPOLONIA, B. L. 1977. Bread staling studies. I. Effect of protein content on staling rate and bread crumb pasting properties. Cereal Chem. 54: 207.

KROG, N., and DAVIS, E. W. 1984. Starch-surfactant interaction related to bread staling - a review. Page U-1 in: International Symposium on Advances in Baking Science and Technology. Dept. of Grain Science and Industry, Kansas State University: Manhattan, KS.

KUGIMIYA, M., and DONOVAN, J. W. 1981. Calorimetric determination of the amylose content of starches based on the formation and melting of the amylose-lysolecithin complex. J. Food Sci. 46: 765.

KUGIMIYA, M., DONOVAN, J. W., and WONG, R. Y. 1980. Phase transitions of amylose-lipid complexes in starches: A calorimetric study. Staerke 32: 265.

KULP, K., and PONTE, J. G., Jr. 1981. Staling of white pan bread: Fundamental causes. Crit. Rev. Food Sci. Nutr. 15(1): 1.

LINEBACK, D. R. 1984. The role of starch in bread staling. Page S-1 in: International Symposium on Advances in Baking Science and Technology. Dept. of Grain Science and Industry, Kansas State University: Manhattan, KS.

LONGLEY, R. W., and MILLER, B. S. 1971. Note on the relative effects of monoglycerides on the gelatinization of wheat starch. Cereal Chem. 48: 81.

MANDELKERN, L. 1958. Crystallization kinetics in polymeric systems. Page 467 in: Growth and Perfection of Crystals. R. H. Doremus, B. W. Robert, and D. Turnbull, eds. John Wiley & Sons, Inc.: New York and Chapman & Hall, Ltd.: London.

MEDCALF, D. G., YOUNGS, V. L., and GILLES, K. A. 1968. Wheat starches. II. Effect of polar and nonpolar lipid fractions on pasting characteristics. Cereal Chem. 45: 88.

MILLER, B. S., DERBY, R. I., and TRIMBO, H. B. 1973. A Pictorial explanation for the increase in viscosity of heated wheat starch-water suspension. Cereal Chem. 50:271.

MORAD, M. M., and D'APPOLONIA, B. L. 1980. Effect of baking procedure and surfactants on the pasting properties of bread crumb. 57: 239.

NISHITA, K. D., and BEAN, M. M. 1979. Physicochemical properties of rice in relation to rice bread. Cereal Chem. 56: 185.

OTT, L. 1984. Pages 365 and 467 in: An Introduction to Statistical Methods and Data Analysis. 2nd ed. Duxbury Press: Boston.

OTT, M., and HESTER, E. E. 1965. Gel formation as related to concentration of amylose and degree of starch swelling. Cereal Chem. 42: 476.

PISESOOKBUNTERNG, W., and D'APPOLONIA, B. L. 1983. Bread staling studies. I. Effect of surfactants on moisture migration from crumb to crust and firmness values of bread crumb. Cereal Chem. 60: 298.

PYLER, E. J. 1973. Keeping properties of bread. Page 804 in: Baking Science and Technology. 2nd ed. Siebel Publishing Co.: Chicago, IL.

RADLEY, J. A. 1960. Solubility patterns of various starches obtained refractometrically. Staerke 12:232.

SARKO, A., and WU, H.-C. H. 1978. The crystal structures of A-, B- and C-polymorphs of amylose and starch. Staerke 30: 73.

SANDSTEDT, R. M., SCHAUMBURG, L., and FLEMING, J. 1954. The microscopic structure of bread and dough. 31:43.

SCHOCH, T. J. 1965. Starch in bakery products. Baker's Dig. 39: 48.

SCHUSTER, G., and ADAMS, W. F. 1984. Emulsifiers as additives in bread and fine baked products.Page 139 in Advances in Cereal Science and Technology. Vol. VI. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

STUTE, R., and KONIECZNY-JANDA, G. 1983. DSC-Untersuchungen an Staerken. Teil II. Untersuchungen an Staerke-Lipid-Komplexen. Staerke 35: 340.

TSEN, C. C. 1984. Interactions of surfactants with flour protein in dough. Page V-1 in: International Symposium on Advances in Baking Science and Technology. Dept. of Grain Science and Industry, Kansas State University: Manhattan, KS.

TSEN, C. C. and HOOVER, W. J. 1971. The shortening-sparing effect of sodium stearoyl-2-lactylate in bread baking. Baker's Dig. 45(3): 38.

ULMANN, M. 1962. Zur chromatographische Kennzeichnung der Starke in Gebacken. I. Das Schicksal der Starke beim Backprozess. Ernahrungsforschung 7: 113.

VARRIANO-MARSTON, E., KE, V., HUANG, G., and PONTE, J. G., Jr. 1980. Comparison of methods to determine starch gelatinization in bakery foods. Cereal Chem. 57: 242.

YASUNAGA, T., BUSHUK, W., and IRVINE, G. N. 1968. Gelatinization of starch during bread-baking. Cereal Chem. 45: 269.

AMYLOGRAPH PROPERTIES OF BREAD CRUMB AND THEIR RELATION TO CRUMB FIRMNESS

by

ANSUI XU

B.E., Wuxi Institute of Light Industry, 1982

AN ABSTRACT OF A MASTER'S THESIS

Submitted in partial fufillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1986

The amylograms of bread crumb suspensions were different from those of flour and starch in that the crumb amylogram had a minor peak before the major peak and a bump during the set-back stage. Wheat flour, wheat starch plus flour lipids, as well as bread crumb, when tested in the amylograph after the first cycle of heating, holding and cooling, all showed the same phenomenon: in both heating and cooling periods, viscosity increased sharply followed by a sharp decrease. Neither defatted flour nor wheat starch alone showed this phenomenon. Therefore, gelatinized starch and lipids were responsible for the unique features of bread crumb amylograms. Presumably, formation and dissociation, crystallization and melting of amylose-lipid complex are involved in the unusual phenomenon. The findings suggest that the amylograph, a relatively simple apparatus, could find more use in the study of starch-lipid interaction.

Sodium stearoyl-2-lactylate (SSL), sucrose monopalmitate (SMP), diacetyl tartaric acid esters of mono- and diglycerides (DATEM), monoglycerides (MG), and petroleum ether-extracted flour lipids were added at the 0.5% level to make breads with and without shortening. The firmness values of loaves were measured after 1, 2 and 5 days of storage at room temperature and the crumbs were then used

for amylograph studies at each storage time. Significant differences were found between amylograph readings of breads made with different treatments, but not between storage days except for the initial pasting temperature. In addition to storage days and loaf volumes, amylograph readings were also necessary to be included in the best-fitting regression equations of crumb firmness as a function of other variables. Correlation coefficients also indicated that amylograph readings of bread crumb were significantly related to crumb firmness. The amylograms of bread crumbs reveal the extent of starch gelatinization which occurred during baking and the interactions between starch and lipids and lipid-related materials, both closely related to crumb firmness and staling.